AFTER@LHC: A Fixed Target ExpeRiment for hadron, heavy-ion and spin physics: Status and short-range plan

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Outline

✓ Advantages of a fixed target experiment at LHC
✓ Internal gas target vs beam extraction with a bent crystal
✓ Expected luminosities
✓ Physics Highlights
✓ Feasibility studies of quarkonium production
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WHAT IS AFTER@LHC AND WHAT FOR?

**AFTER@LHC is a proposal for a multi-purpose fixed target experiment using the multi-TeV proton or heavy ion beams of the LHC**

• Advance our understanding of the large-x gluon antiquark and heavy-quark content in the nucleon and nucleus
• Dynamics and spin of gluons inside (un)polarised nucleons
• Heavy-ion collisions towards large rapidities
Advantages of a fixed-target experiment at LHC

✓ Advantages of a fixed-target experiment:
  • high luminosities with dense targets
  • target versatility
  • possibility to polarize target ➢ spin physics program
  • access to large Feynman $|x_F|$

➢ With LHC beams:

7 TeV proton beam on a fixed target

| CMS energy: $\sqrt{s} = \sqrt{2m_N E_p} \approx 115$ GeV |
| Boost: $\gamma = \sqrt{s} / (2m_p) \approx 60$ |
| Rapidity shift: $y_{CM} = 0 \rightarrow y_{lab} = 4.8$ |

2.76 TeV Pb beam on a fixed target

| CMS energy: $\sqrt{s_{NN}} = \sqrt{2m_N E_{Pb}} \approx 72$ GeV |
| Boost: $\gamma \approx 40$ |
| Rapidity shift: $y_{CM} = 0 \rightarrow y_{lab} = 4.3$ |
Advantages of a fixed target experiment at LHC

✓ Testing QCD at large $x = (0.3,1)$

✓ Entire forward hemisphere – $y_{CM} > 0$ – within: $0^\circ < \theta_{lab} < 1^\circ$ - large occupancy – more challenging

✓ Backward region - $y_{CM} < 0$ – at large angles in the lab frame – low occupancy, no constrain from a beam pipe
  • Backward physics accessible
  • Access to partons with momentum fraction $x_2 \rightarrow 1$ in the target ($x_F \rightarrow -1$)
Possible fixed-target mode

**UA9:** test @SPS on the crystal with proton and ion beams **LUA9** (beam bending experiment using crystal): approved by LHCC

- 2 bent crystals installed in IR7 during LS1, 2015/2016 first tests with beams

**Proton beam extraction:**

- Single or multi-pass extraction efficiency of 50%

  - LHC beam loss $\sim 10^{9} \text{p}^{+} \text{s}^{-1}$ - extracted beam: $5 \times 10^{8} \text{p}^{+} \text{s}^{-1}$

**Ion beam extraction**

- Successfully tested at the SPS, should also work at the LHC (P. Ballin et al, NIMB 267 (2009) 2952)
Beam extraction using bent crystal

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$\rightarrow$ Deflecting the beam halo at $7\sigma$ distance to the beam
$\rightarrow$ **No loss in the LHC beam**
Internal gas target, *SMOG@LHC*

**Possible fixed-target mode**

- Low density Ne-gas injected into VELO in LHCb
- Short pNe pilot run at $\sqrt{s_{NN}} = 87$ GeV in 2012
  
  *LHCb-CONF-2012-034*

- Short PbNe pilot run at $\sqrt{s_{NN}} = 54$ GeV in 2013

  Ne target density: $1.5 \times 10^{-7}$ mbar

- Noble gases favored
- As for now, target polarization is not possible with SMOG
- *Internal gas target can be polarized*, would be another system with respect to SMOG
Luminosities in $pH$ and $pA$ at $\sqrt{s_{NN}} = 115$ GeV

- **Instantaneous luminosity:**
  \[ L = \phi_{\text{beam}} \times N_{\text{target}} = \phi_{\text{beam}} \times (\rho \times l \times N_A) / A \]

  $l$ is a target thickness

- $\phi_{\text{beam}} = 5 \times 10^8 \text{ p}^+ \text{ s}^{-1}$ (50% of the beam loss)

- **Integrated luminosity** - LHC year – 9 months running = $10^7$ s

<table>
<thead>
<tr>
<th>Target</th>
<th>$\rho$ (g.cm$^{-3}$)</th>
<th>A</th>
<th>$L$ (μb$^{-1}$s$^{-1}$)</th>
<th>$\int L$ (pb$^{-1}$yr$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liq H$_2$ (1m)</td>
<td>0.07</td>
<td>1</td>
<td>2000</td>
<td>20000</td>
</tr>
<tr>
<td>Liq D$_2$ (1m)</td>
<td>0.16</td>
<td>2</td>
<td>2400</td>
<td>24000</td>
</tr>
<tr>
<td>Be (1cm)</td>
<td>1.85</td>
<td>9</td>
<td>62</td>
<td>620</td>
</tr>
<tr>
<td>Cu (1cm)</td>
<td>8.96</td>
<td>64</td>
<td>42</td>
<td>420</td>
</tr>
<tr>
<td>W (1cm)</td>
<td>19.1</td>
<td>185</td>
<td>31</td>
<td>310</td>
</tr>
<tr>
<td>Pb (1cm)</td>
<td>11.35</td>
<td>207</td>
<td>16</td>
<td>160</td>
</tr>
</tbody>
</table>

- Large luminosities comparable to LHC - with 1 m long H$_2$(D$_2$) target, 3 orders of magnitude larger that at RHIC
Higher instantaneous luminosities using a bent crystal compare to what is expected from SMOG from the pilot run - 62 $\mu$b$^{-1}$s$^{-1}$ with 1cm Be target vs 8 $\mu$b$^{-1}$s$^{-1}$ for Ne in SMOG.

Higher Ne pressure needed in SMOG in order to reach comparable luminosity as in the bent crystal case.

assuming 1 year of running with a proton beam and $P \approx 10^{-5}$ mbar, one can obtain comparable luminosity as in the bent crystal case.

- Increasing the pressure is not expected to decrease the beam life time.
Luminosities in PbA at $\sqrt{s_{NN}} = 72$ GeV

- Instantaneous luminosity:
  \[ L = \phi_{\text{beam}} \times N_{\text{target}} = \phi_{\text{beam}} \times (\rho \times l \times N_A) / A \]

- $\phi_{\text{beam}} = 2 \times 10^5$ Pb s$^{-1}$

- Integrated luminosity - LHC year – 1 month running = $10^6$ s

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- Nominal LHC luminosity for PbPb 0.5 nb$^{-1}$
Physics Highlights: AFTER@LHC


Many more ideas for a fixed target experiment at LHC submitted to a Special Issue in Advances in High Energy Physics

http://after.in2p3.fr/after/index.php/Recent_published_ideas_in_favour_of_AFTER@LHC

Heavy-ion physics

Exclusive reactions

Spin physics studies

Hadron structure

Feasibility study and technical ideas
Physics Highlights: AFTER@LHC

pp and pA @ $\sqrt{s_{NN}} = 115$ GeV

- **Understand dynamic of large-x gluon in nucleon**

  - Quarkonia, Isolated photons, High-$p_T$ jets (> 20 GeV/c)
  
  - Gluon distribution function in the proton: very large uncertainty at large $x_B$, also at large $Q$
  
  - Unknown for the neutron
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- Heavy-quark distribution at large $x$
  - Open charm and beauty
  - Pin down intrinsic charm
    • Intrinsic heavy quarks are rigorous features of QCD
    • Different charm pdfs (DGLAP or models with intrinsic charm) are in agreement with DIS data


CTEQ6.5C with intrinsic charm

Physics Highlights: AFTER@LHC
pp and pA @ $\sqrt{s_{NN}} = 115$ GeV

- **Understand dynamic of large-x gluon in nucleon**
  - Quarkonia, Isolated photons, High-$p_T$ jets (> 20 GeV/c)
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  - Intrinsic heavy quarks are rigorous features of QCD
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- With AFTER@LHC
  - Good coverage in the target rapidity region
  - High luminosity to reach large $x_B$
  - Different targets: hydrogen, deuteron (neutron)

Physics Highlights: AFTER@LHC

pp and pA @ $\sqrt{s_{\text{NN}}} = 115$ GeV

✓ Nucleon partonic structure

• Gluon pdf in the proton – large uncertainties at high $x$

  $g_p(x) = g_n(x)$ ?

  → Measure: quarkonia, isolated photons, high-$p_T$ jets

  → Multiple probes to check factorization

✓ Heavy-quark distribution at large $x$ in the proton

  → Measure: open heavy flavours

✓ Spin physics

• Gluon Sivers effect

• Linearly polarized gluons: $h_{1g}^{\perp}$, “Boers-Mulder” effect

• Single Spin Asymmetry in DY and HF studies

See also: arXiv:1502.04021;
arXiv:1504.03791; arXiv:1504.04332,

✓ $W$ and $Z$ production near threshold ?

With AFTER@LHC: boost – better access to the low-$p_T$, C-even quarkonia
Physics Highlights: AFTER@LHC
\[PbA @ \sqrt{s_{NN}} = 72 \text{ GeV}, \ pA @ \sqrt{s_{NN}} = 115 \text{ GeV}\]

- **Gluon distribution in nucleus at large x**
  - Quarkonia
  - Isolated photons
  - High-\(p_T\) jets (> 20 GeV/c)
  - Large uncertainty in nuclei at large x, unknown gluon EMC effect
  - With AFTER@LHC:
    - Access to target \(x_g = 0.3 - 1\) (>1 Fermi motion in nucleus)
    - With different targets:
      - Probing A dependence of shadowing and nuclear matter effects
Gluon distribution in nucleus at large $x$
- Complementary to EIC, LHeC
  - Quarkonia, isolated photons, high-$p_T$ jets

Quark-Gluon Plasma
- Experimental probes
  - Quarkonia
  - HF jets quenching
  - Low mass lepton pairs
  - Direct photons
    - (Sequential?) suppression of different quarkonium states – good resolution needed
    - In PbA, different nuclei, A-dependent studies
    - Precise estimation of Cold Nuclear Matter effects from pA

Ultra-peripheral collisions
First simulations

Feasibility studies for quarkonium production at a fixed-target experiment using the LHC proton and lead beams (AFTER@LHC)

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2IPNO, Université Paris-Sud, CNRS/IN2P3, F-91406, Orsay, France
3FNSPE, Czech Technical U., Prague, Czech Republic
4Laboratoire Leprince Ringuet, École Polytechnique, CNRS/IN2P3, 91128 Palaiseau, France
5Faculty of Physics, Warsaw University of Technology, ul. Koszykowa 75, 00-662 Warsaw, Poland
6PH Department, TH Unit, CERN, CH-1211, Geneva 23, Switzerland

(Dated: June 17, 2015)

Used in the fixed-target mode, the multi-TeV LHC proton and lead beams allow for studies of heavy-flavour hadroproduction with unprecedented precision at backward rapidities –far negative Feynman-x– using conventional detection techniques. At the nominal LHC energies, quarkonia can be studied in detail in \( p + p \), \( p + d \) and \( p + A \) collisions at \( \sqrt{s_{NN}} = 115 \text{ GeV} \) as well as in \( \text{Pb} + p \) and \( \text{Pb} + A \) collisions at \( \sqrt{s_{NN}} = 72 \text{ GeV} \) with luminosities roughly equivalent to that of the collider mode, i.e. up to 20 fb\(^{-1}\) year\(^{-1}\) in \( p + p \) and \( p + d \) collisions, up to 0.6 fb\(^{-1}\) year\(^{-1}\) in \( p + A \) collisions and up to 10 nb\(^{-1}\) year\(^{-1}\) in \( \text{Pb} + A \) collisions. In this paper, we assess the feasibility of such studies by performing fast simulations using the performance of a LHCb-like detector.

\textit{arXiv: 1504.5145}
Charge particle multiplicities, for all possible fixed target modes, p+Pb, Pb+H, Pb+Pb, are smaller than the ones reached in the collider modes. A detector with the LHCb capabilities will be able to run in such conditions (LHCb was used in p+Pb and Pb+p at 5 TeV).
**Expected quarkonium yield**

pp and pA @ √s = 115 GeV

### pp

- **1 m H₂ target**
  - 1000 times more statistics than at RHIC (@200 GeV)
  - Comparable statistics to LHC

<table>
<thead>
<tr>
<th>Target</th>
<th>∫L (fb⁻¹.yr⁻¹)</th>
<th>N(J/Ψ) yr⁻¹ (A L²σ)</th>
<th>N(ϒ) yr⁻¹ (A L²σ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m Liq. H₂</td>
<td>20</td>
<td>4.0 10⁸</td>
<td>8.0 10⁵</td>
</tr>
<tr>
<td>1 m Liq. D₂</td>
<td>24</td>
<td>9.6 10⁸</td>
<td>1.9 10⁶</td>
</tr>
<tr>
<td>LHC pp 14 TeV (low pT)</td>
<td>0.05 (ALICE) 2 LHCb</td>
<td>3.6 10⁷ (1.4 10⁵)</td>
<td>1.8 10⁵ (7.2 10⁶)</td>
</tr>
<tr>
<td>RHIC pp 200GeV</td>
<td>1.2 10⁻²</td>
<td>4.8 10⁵</td>
<td>1.2 10³</td>
</tr>
</tbody>
</table>

### pA

- **1 cm Pb target**
  - 100 times more statistics than at RHIC (dAu@200 GeV)
  - Comparable statistics to LHC

<table>
<thead>
<tr>
<th>Target</th>
<th>A</th>
<th>∫L (fb⁻¹.yr⁻¹)</th>
<th>N(J/Ψ) yr⁻¹ (A L²σ)</th>
<th>N(ϒ) yr⁻¹ (A L²σ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1cm Be</td>
<td>9</td>
<td>0.62</td>
<td>1.1 10⁸</td>
<td>2.2 10⁵</td>
</tr>
<tr>
<td>1cm Cu</td>
<td>64</td>
<td>0.42</td>
<td>5.3 10⁸</td>
<td>1.1 10⁶</td>
</tr>
<tr>
<td>1cm W</td>
<td>185</td>
<td>0.31</td>
<td>1.1 10⁹</td>
<td>2.3 10⁶</td>
</tr>
<tr>
<td>1cm Pb</td>
<td>207</td>
<td>0.16</td>
<td>6.7 10⁸</td>
<td>1.3 10⁶</td>
</tr>
<tr>
<td>LHC pPb 8.8 TeV</td>
<td>207</td>
<td>10⁻⁴</td>
<td>1.0 10⁷</td>
<td>7.5 10⁴</td>
</tr>
<tr>
<td>RHIC dAu 200GeV</td>
<td>198</td>
<td>1.5 10⁻⁴</td>
<td>2.4 10⁶</td>
<td>5.9 10³</td>
</tr>
<tr>
<td>RHIC dAu 62GeV</td>
<td>198</td>
<td>3.8 10⁻⁶</td>
<td>1.2 10⁴</td>
<td>18</td>
</tr>
</tbody>
</table>

See also: Advances in High Energy Physics, Article ID 726393, in press.  
arXiv:1504.0653
# Expected quarkonium yield

\[ \text{PbA@} \sqrt{s_{NN}} = 72 \text{ GeV} \]

<table>
<thead>
<tr>
<th>Target</th>
<th>A.B</th>
<th>( \int \mathcal{L} \text{ (nb}^{-1}\text{.yr}^{-1}) )</th>
<th>( \frac{N(J/\Psi) \text{ yr}^{-1}}{AB \mathcal{L} B \sigma_{\Psi}} )</th>
<th>( \frac{N(\Upsilon) \text{ yr}^{-1}}{AB \mathcal{L} B \sigma_{\Upsilon}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m Liq. H(_2)</td>
<td>207.1</td>
<td>800</td>
<td>3.4 \times 10^6</td>
<td>6.9 \times 10^3</td>
</tr>
<tr>
<td>1 cm Be</td>
<td>207.9</td>
<td>25</td>
<td>9.1 \times 10^5</td>
<td>1.9 \times 10^3</td>
</tr>
<tr>
<td>1 cm Cu</td>
<td>207.64</td>
<td>17</td>
<td>4.3 \times 10^6</td>
<td>0.9 \times 10^3</td>
</tr>
<tr>
<td>1 cm W</td>
<td>207.185</td>
<td>13</td>
<td>9.7 \times 10^6</td>
<td>1.9 \times 10^3</td>
</tr>
<tr>
<td>1 cm Pb</td>
<td>207.207</td>
<td>7</td>
<td>5.7 \times 10^6</td>
<td>1.1 \times 10^4</td>
</tr>
<tr>
<td>LHC PbPb 5.5 TeV</td>
<td>207.207</td>
<td>0.5</td>
<td>7.3 \times 10^6</td>
<td>3.6 \times 10^4</td>
</tr>
<tr>
<td>RHIC AuAu 200GeV</td>
<td>198.198</td>
<td>2.8</td>
<td>4.4 \times 10^6</td>
<td>1.1 \times 10^4</td>
</tr>
<tr>
<td>RHIC AuAu 62GeV</td>
<td>198.198</td>
<td>0.13</td>
<td>4.0 \times 10^4</td>
<td>61</td>
</tr>
</tbody>
</table>

- **1 cm Pb target**
  - Similar statistics than at RHIC @200 GeV
  - 2 order of magnitude larger that at RHIC @62 GeV

**Detailed study of quarkonium states**
First simulations of quarkonia, \( pp \) at \( \sqrt{s} = 115 \) GeV

- PYTHIA 8.185, fast simulations with LHCb-like reconstruction parameters

  ✓ **Requirements:**
  - Momentum resolution: \( \Delta p/p = 0.5\% \)
  - \( \mu \) identification efficiency: 98%

  ✓ **Single \( \mu \) cuts:**
  - \( 2 < \eta_{\mu} < 5 \)
  - \( p_T^{\mu} > 0.7 \) GeV/c

  ✓ **\( \mu \) misidentification (with \( \pi \) or \( K \))**

  ✓ **Input for quarkonium signals:**
  - HELAC-Onia

  ✓ **Estimation of different dimuon background sources:**
  - Uncorrelated background – min bias PYTHIA 8
  - Drell-Yan – HELAC-Onia
  - cc, bb – HELAC-Onia

**Efficiency of background \( \mu \) pairs**
ψ and γ signal simulations with full background

\[ J/\psi / \psi(2S) \rightarrow \mu^+ \mu^- \]
\[ \Upsilon(nS) \rightarrow \mu^+ \mu^- \]

\[ \int L = 10 \text{ fb}^{-1}, \text{0.5 year of data taking with 1m H}_2 \text{ target (in the crystal case)} \]

- Dominant source of background is uncorrelated background
- Dominant source of background is DY
- Clear separation of different states
$J/\psi$ signal simulation with full background \quad $J/\psi \rightarrow \mu^+ \mu^-$

$\int L = 10 \text{ fb}^{-1}$, **0.5 year of data taking with 1m H$_2$ target** (in the crystal case)

- $p_T$ and rapidity Distributions for the $J/\psi$ and different backgrounds differ.
- In more backward or forward rapidity regions, the signal to background ratio increases
Quarkonium acceptance and $p_T$ reach

\[ \int \mathcal{L} = 10 \text{ fb}^{-1}, \textbf{0.5 year of data taking with 1m H}_2 \textbf{ target} \] (in the crystal case)

- $J/\psi$ and $\psi(2S)$ signals can be studied up to $\sim 15 \text{ GeV/c}$, $\Upsilon(nS)$ up to $\sim 10 \text{ GeV/c}$
- All quarkonium states can be measured down to 0 GeV/c
- Similar $p_T$ reach expected for pA

- Study is limited to the rapidity range of $2 < y < 5 \ (2 < \eta_\mu < 5)$
- $J/\psi$ and $\psi(2S)$ signals can be studied in the whole range, lowest $y$ for $\Upsilon(nS)$ is $\sim 2.5-3$
Impact of nPDF effects on quarkonium $R_{pPb}$

- Combination of measurements of $\Upsilon(nS)$, $J/\psi$ and $\psi(2S)$ for $-3 < y_{CMS} < 0$ (as LHCb detector would do) will allow to pin down the existence of a possible gluon EMC and antishadowing effect.

Simulations done using JIN with EPS09

Very good statistical precision!

See also: Advances in High Energy Physics, Article ID 492302 and 783134, in press; arXiv:1507.05413; arXiv:1504.07428

pp: $\int L = 10 \text{ fb}^{-1}$, pPb: $\int L = 100 \text{ pb}^{-1}$
Summary

➢ Many physics opportunities with a fixed target experiment using LHC p and Pb beams
➢ Novel testing ground for QCD in the high-x frontier with AFTER@LHC
➢ Extensive spin program with a polarized target
➢ Using dense targets high luminosities can be achieved
➢ Target versatility: hydrogen, deuteron, nucleus – nuclear effects and QGP
➢ First fast simulations performed
   ➔ Simulations in pA, AA and of different quarkonium states in progress

Thank you!
BACKUP
Outlook

➢ Special Issue in Advances in High Energy Physics
➢ Expression of interest expected in 2015/2016
➢ Development of the fast simulation framework

after.in2p3.fr
Beam extraction using bent crystal

✓ Possible fixed-target mode

Standard collimation today

Crystal-based collimation
- UA9 (@SPS)
- LUA9 (@LHC)

To beam extraction
- CRYSBEAM (@SPS then LHC)
- AFTER@LHC

W. Scandale et al., JINST 6 T10002 (2011)

UA9 experiment @ SPS, 15/10/2014

S. Montesano, W. Scandale, Joint LUA9-AFTER meeting, Nov. 2013
Beam extraction using bent crystal

✓ Beam collimation @LHC: amorphous collimator, inefficiency of 0.2% (3.5 TeV p beam)
  • Expected bent crystal inefficiency: 0.02%

UA9: test @SPS on the crystal with proton and ion beams
LUA9 (beam bending experiment using crystal): approved by LHCC
  2 bent crystals installed in IR7 during LS1
  2015/2016 first tests with beams

➢ Proton beam extraction:
  • Single or multi-pass extraction efficiency of 50%
  • LHC beam loss ~ $10^9 \text{p}^+ \text{s}^{-1}$ - extracted beam: $5 \times 10^8 \text{p}^+ \text{s}^{-1}$
  • Extremely small emittance: beam size (in the extraction direction) 950m after the extraction: 0.3mm

➢ Ion beam extraction
  • Successfully tested at the SPS, should also work at the LHC (P. Ballin et al, NIMB 267 (2009) 2952)

→ Deflecting the beam halo at $7\sigma$ distance to the beam
  → No loss in the LHC beam
Physics Highlights: AFTER @ LHC

pp and pA @\( \sqrt{s_{NN}} = 115 \) GeV

(Gluon) Sivers effects with a transversely polarized target

Gluon Sivers effect: correlation between the gluon transverse momentum \( k_T \) and the proton spin

- The target rapidity region \( (x_F < 0) \) corresponds to high \( x \uparrow \) \( (x_F \rightarrow -1) \) where the \( k_T \)-spin correlation is the largest

- Transverse single spin asymmetries studied using gluon sensitives probes:
  - quarkonia \( (J/\psi, \ U, \chi_c) \)
  - B & D mesons production
  - \( \gamma, \gamma\text{-jet}, \gamma\text{-}\gamma \) also \( J/\psi\text{-}\gamma \)

L. Massacrier – SPIN 2014
Conference
Physics Highlights: AFTER @ LHC

pp and pA @ $\sqrt{s_{NN}} = 115$ GeV

TMDs STUDIES WITH AFTER@LHC (WITH A POLARIZED TARGET)

(Quark) Sivers effects with a transversely polarized target

- Can be probed with the Drell-Yan

<table>
<thead>
<tr>
<th>Experiment</th>
<th>particles</th>
<th>energy (GeV)</th>
<th>$\sqrt{s}$ (GeV)</th>
<th>$x_F$</th>
<th>$\mathcal{L}$ (nb$^{-1}$s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFTER</td>
<td>$p+p^\uparrow$</td>
<td>7000</td>
<td>115</td>
<td>0.01 \pm 0.9</td>
<td>1</td>
</tr>
<tr>
<td>COMPASS</td>
<td>$\pi^\pm + p^\uparrow$</td>
<td>160</td>
<td>17.4</td>
<td>0.2 \pm 0.3</td>
<td>2</td>
</tr>
<tr>
<td>COMPASS</td>
<td>$\pi^\pm + p^\uparrow$</td>
<td>160</td>
<td>17.4</td>
<td>\sim 0.05</td>
<td>2</td>
</tr>
<tr>
<td>RHIC</td>
<td>$p^\uparrow + p$</td>
<td>collider</td>
<td>500</td>
<td>0.05 \pm 0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>J–PARC</td>
<td>$p^\uparrow + p$</td>
<td>50</td>
<td>10</td>
<td>0.5 \pm 0.9</td>
<td>1000</td>
</tr>
<tr>
<td>PANDA</td>
<td>$\bar{p} + p^\uparrow$</td>
<td>15</td>
<td>5.5</td>
<td>0.2 \pm 0.4</td>
<td>0.2</td>
</tr>
<tr>
<td>(low mass)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PAX</td>
<td>$p^\uparrow + \bar{p}$</td>
<td>collider</td>
<td>14</td>
<td>0.1 \pm 0.9</td>
<td>0.002</td>
</tr>
<tr>
<td>NICA</td>
<td>$p^\uparrow + \bar{p}$</td>
<td>collider</td>
<td>20</td>
<td>0.1 \pm 0.8</td>
<td>0.001</td>
</tr>
<tr>
<td>RHIC</td>
<td>$p^\uparrow + p$</td>
<td>250</td>
<td>22</td>
<td>0.2 \pm 0.5</td>
<td>2</td>
</tr>
<tr>
<td>Int. Target 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Int. Target 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P1027</td>
<td>$p^\uparrow + p$</td>
<td>120</td>
<td>15</td>
<td>0.35 \pm 0.85</td>
<td>400-1000</td>
</tr>
<tr>
<td>P1039</td>
<td>$p^\uparrow + p$</td>
<td>120</td>
<td>15</td>
<td>0.1 \pm 0.3</td>
<td>400-1000</td>
</tr>
</tbody>
</table>

Relevant parameters for the future proposed polarized DY experiments


Asymmetry up to 10% predicted in DY for the target rapidity region ($x_F < 0$)

L. Massacrier – SPIN 2014 Conference

M. Anselmo, ECT*, Feb. 2013
(Courtesy U. d’Alessio)
Physics Highlights: AFTER@LHC

pp and pA @ $\sqrt{s_{NN}} = 115$ GeV

- **Linearly polarized gluons:** $h_1^{Lg}$
  - "Boers-Mulder" effect: correlation between the parton $k_T$ and its spin (in unpolarized nucleon)
  - Scalar and pseudo-scalar quarkonia – $\chi_{c0}$, $\chi_{b0}$, $\eta_c$, $\eta_b$

- Low-$p_T$ C-even quarkonium production is a good probe of gluon Transverse Momentum Dependent (TMD) pdfs
- Low-$p_T$ scalar and pseudo-scalar quarkonia are affected differently by the linearly polarized gluons in unpolarized nucleons
- With AFTER@LHC
  - Boost – better access to the low-$p_T$ C-even quarkonia
  - $\eta_c$ (LHCb 1409.3612), ($\eta_b$), back-to-back $J/\psi + \gamma$, $J/\psi + J/\psi$
ψ signal simulation with full background

\[ J/\psi / \psi(2S) \rightarrow \mu^+ \mu^- \]

- In more backward or forward rapidity regions, the signal to background ratio increases